

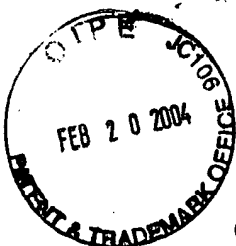
FEB.16.2004

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HARRIS GCSD

NO.986

P.1

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:)
GOLDSTEIN)
Serial No. 10/060,497) Examiner: H. Le
Filing Date: JANUARY 30, 2002) Art Unit: 2821
For: PHASED ARRAY ANTENNA INCLUDING)
ARCHIMEDEAN SPIRAL ELEMENT)
ARRAY AND RELATED METHODS)

RECEIVED

DECLARATION UNDER 37 CFR 1.131

FEB 26 2004

MS Non-Fee Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, M. Lawrence Goldstein, hereby declare that:

1. I am the sole inventor for the above-identified patent application.

2. Prior to July 11, 2001, I conceived and reduced to practice the invention as described and claimed in the subject patent application, as evidenced by the following documents:

(a) a printout of a MathCAD analysis for an Archimedean spiral lattice that I personally prepared prior to July 11, 2001, which is attached hereto as Appendix A (note the definition of the Archimedean spiral lattice on page 1, and graph

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NO.986 P.2

In re Patent Application of:
GOLDSTEIN
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and simulation results thereof provided on page 4); and

(b) a printout of a power point presentation also personally prepared by myself prior to July 11, 2001, which is attached hereto as Appendix B, demonstrating MathCAD simulation results for various test configurations of my Archimedean spiral lattice (see pages 1-3 and 9), and also providing Mathcad simulation results for various prior art arrays (namely an aperiodic concentric ring lattice on page 4, and various periodic triangular lattices on pages 5-8) for comparison purposes.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

2/16/03
Date

M. Lawrence Goldstein
M. Lawrence Goldstein

The Element

$$\text{csgain}(\theta, n) := 10 \cdot \log \left[\frac{2 \cdot (|\cos(\theta)|)^n}{\int_0^{\pi \cdot 0.5} (|\cos(\theta)|)^n \cdot \sin(\theta) \, d\theta} \right]$$

cos^n pattern

$$\text{ElementGain}(\theta) := \text{csgain}(\theta, 2.155) \quad \text{ElementGain}(0\text{-deg}) = 8$$

Element gain vs. scan

$$c := 2.997925 \cdot 10^8 \frac{\text{m}}{\text{sec}} \quad \lambda := \frac{c}{f} \quad k_0 := 2 \cdot \frac{\pi}{\lambda}$$

frequency

$$G_{\text{array}} := 10 \cdot \log(N) + \text{ElementGain}(0\text{-deg})$$

maximum possible array gain (boresight)

The Array

$$\begin{array}{l} \text{Next}(\theta_1) := \Delta\theta \leftarrow 10\text{-deg} \\ \theta_2 \leftarrow \theta_1 + \Delta\theta \\ \text{for } i \in 1..5 \\ \quad \theta_2 \leftarrow \theta_2 - \Delta\theta \\ \quad \Delta\theta \leftarrow \frac{\Delta\theta}{10} \\ \quad \text{while } 4 \cdot \pi^2 \geq \theta_1^2 + \theta_2^2 - 2 \cdot \theta_1 \cdot \theta_2 \cdot \cos(\theta_1 - \theta_2) \\ \quad \quad \theta_2 \leftarrow \theta_2 + \Delta\theta \\ \theta_2 \end{array}$$

angles for spiral lattice

The Subarray

$$\text{ElementGain}(0\text{-deg}) \quad s := 10 \quad \frac{\lambda}{20} \cdot \frac{\lambda}{\pi} \quad s = 1.123 \text{ in}$$

required min spacing

$$\theta_{s_i} := 0\text{-deg} \quad i := 2..N \quad \theta_{s_i} := \text{Next}(\theta_{s_{i-1}}) \quad i := 1..N \quad d_{i,1} := \theta_{s_i} \cdot \cos(\theta_{s_i}) \cdot \frac{s}{2\pi} \quad d_{i,2} := \theta_{s_i} \cdot \sin(\theta_{s_i}) \cdot \frac{s}{2\pi}$$

array lattice

$$k := 1..N \quad \Delta d_{i,k} := \text{if } [i = k, 1000\text{-in}, \sqrt{(d_{i,1} - d_{k,1})^2 + (d_{i,2} - d_{k,2})^2}] \min(\Delta d) = 1.119 \text{ in}$$

min spacing

$$D := \max \left(\sqrt{\left(\overrightarrow{d^{(1)}} \right)^2 + \left(\overrightarrow{d^{(2)}} \right)^2} \right) \cdot 2 + s \quad \eta := N \cdot \left(\frac{s}{D} \right)^2$$

aperture efficiency

Beamforming

$$PQ(\alpha) := \text{round} \left(\frac{\alpha \cdot 2^{\text{nbits}}}{2 \cdot \pi} \right) \cdot \frac{2 \cdot \pi}{2^{\text{nbits}}}$$

phase quantization for an n-bit phase shifter

$$\text{Err}(x) := x \cdot \left[10^{\frac{\text{rnd}(\text{MagErr}) - 0.5 \cdot \text{MagErr}}{20}} \cdot e^{j \cdot [(\text{rnd}(\text{PhaseErr}) - 0.5 \cdot \text{PhaseErr}) \cdot \text{deg}]} \right]$$

random mag & phase errors

$$w_i := \text{Err} \left[e^{j \cdot PQ \left[k_o \cdot \sin(\theta_o) \cdot \left[\left(\frac{\langle 1 \rangle}{d} \right)_i \cdot \cos(\phi_o) + \left(\frac{\langle 2 \rangle}{d} \right)_i \cdot \sin(\phi_o) \right] \right]} \right] \quad P_t := \sum_i (|w_i|)^2$$

array element weights

$$AG(\theta, \phi) := 10 \cdot \log \left[\frac{\left[\sum_i w_i \cdot e^{-j \cdot k_o \cdot \sin(\theta) \cdot \left[\left(\frac{\langle 1 \rangle}{d} \right)_i \cdot \cos(\phi) + \left(\frac{\langle 2 \rangle}{d} \right)_i \cdot \sin(\phi) \right]} \right]^2}{P_t} \right] + \text{ElementGain}(\theta)$$

array gain

$$\Delta\theta := 1 \cdot \text{deg} \quad N\theta := \frac{90 \cdot \text{deg}}{\Delta\theta} + 1 \quad \theta_i := 1 \dots N\theta \quad \theta_{\theta i} := (\theta_i - 1) \cdot \Delta\theta$$

elevation cut points

$$\Delta\phi := 3 \cdot \text{deg} \quad N\phi := \frac{360 \cdot \text{deg}}{\Delta\phi} \quad \phi_i := 1 \dots N\phi \quad \phi_{\phi i} := (\phi_i - 1) \cdot \Delta\phi$$

azimuth cut points

$$\text{MBG} := AG(\theta_o, \phi_o)$$

main beam gain

$$\text{BW}(\text{cut}, \Delta\psi) :=$$

null-to-null beamwidth

```

pt ← max(cut)
for i ∈ 1..rows(cut)
  indx ← i if cuti = pt
  i1 ← indx
  while cuti1+1 ≤ cuti1 ∨ cuti1+2 ≤ cuti1 ∨ cuti1+3 ≤ cuti1
    i1 ← i1 + 1
  i2 ← indx
  while cuti2-1 ≤ cuti2 ∨ cuti2-2 ≤ cuti2 ∨ cuti2-3 ≤ cuti2
    i2 ← i2 - 1
  (i1 - i2) · Δψ

```

HPBW(cut, $\Delta\psi$) :=

```

    pt ← max(cut)
    for i ∈ 1..rows(cut)
        indx ← i if cuti = pt
    i1 ← indx
    while cuti1+1 > pt - 3
        i1 ← i1 + 1
    i2 ← indx
    while cuti2-1 > pt - 3
        i2 ← i2 - 1
    (i1 - i2 + 1) · Δψ

```

$\phi_{cut\phi_i} := AG(\theta_o, \phi_{\phi_i}) - MBG$ $BW_{\phi} := BW(\phi_{cut}, \Delta\phi)$ $BW_{\phi} = 36 \text{ deg}$ normalized phi cut & beamwidth
 $\theta_{cut\theta_j} := AG(\theta_{\theta_i}, \phi_o) - MBG$ $BW_{\theta} := BW(\theta_{cut}, \Delta\theta)$ $BW_{\theta} = 20 \text{ deg}$ normalized theta cut & beamwidth
 HPBW $_{\theta} := HPBW(\theta_{cut}, \Delta\theta)$ HPBW $_{\phi} := HPBW(\phi_{cut}, \Delta\phi)$ HPBWS

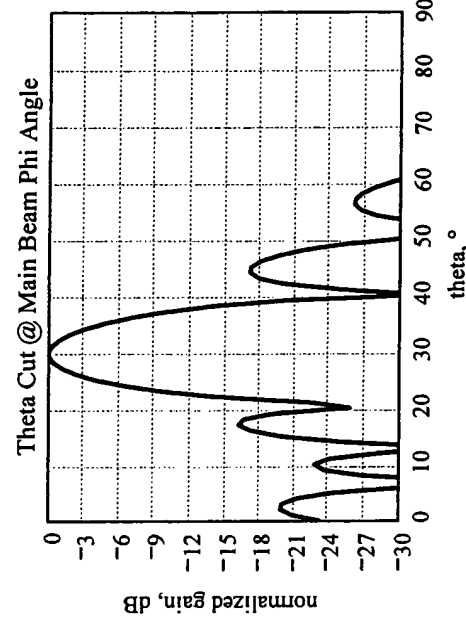
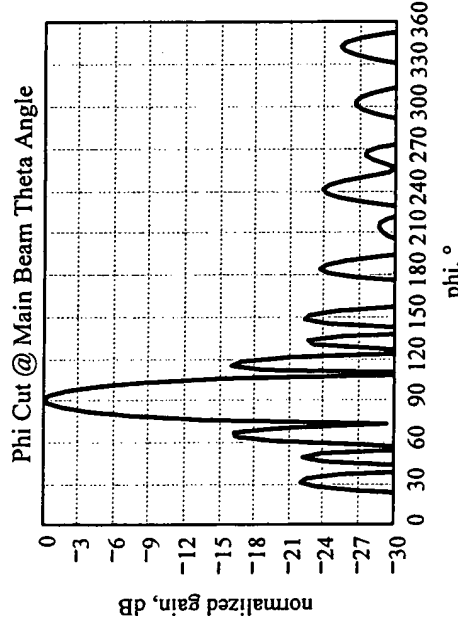
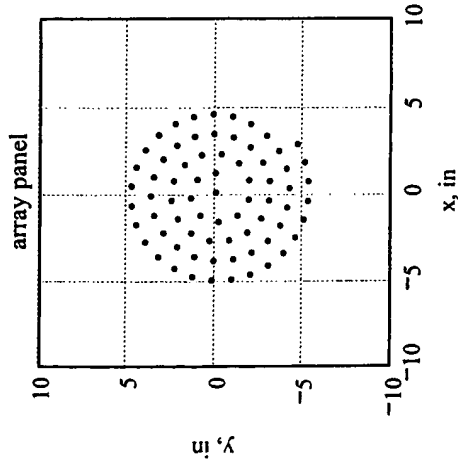
$Hemi_{\phi_i, \theta_i} := AG(\theta_{\theta_i}, \phi_{\phi_i}) - MBG$ $Hemi_{\phi_i, \theta_i} := \text{if}(Hemi_{\phi_i, \theta_i} < SLL_{goal} - 0.5, SLL_{goal} - 0.5, Hemi_{\phi_i, \theta_i})$ all hemispherical pattern normalized & clipped

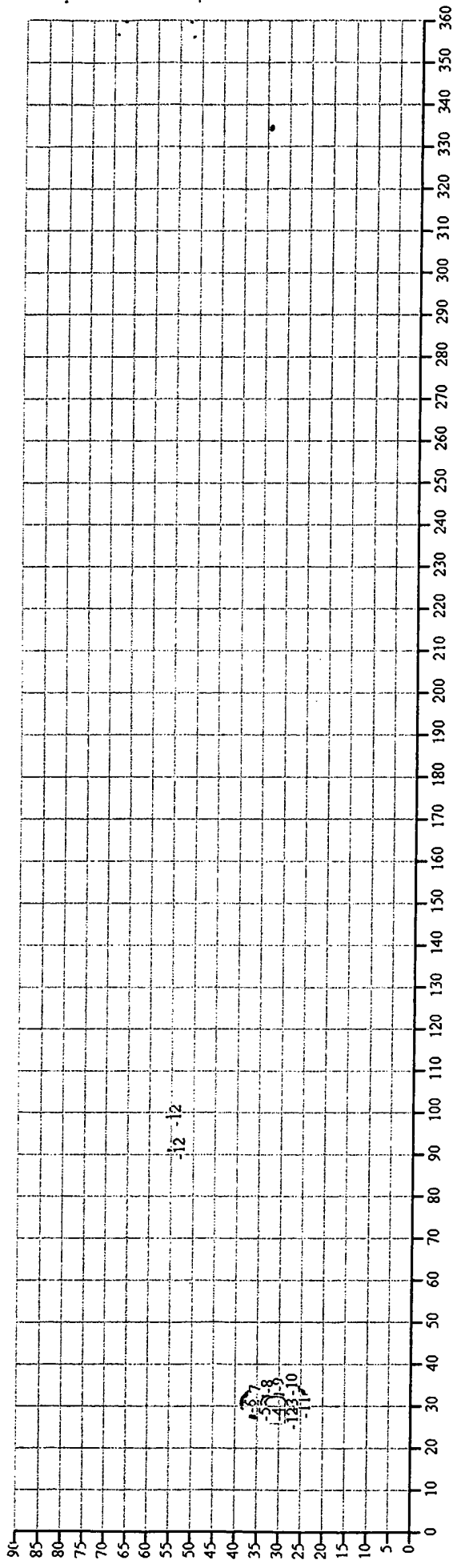
SLLcompliance :=

$$\frac{cnt}{N\phi \cdot N\theta}$$
 for i ∈ 1..N θ
 for k ∈ 1..N ϕ
 cnt ← cnt + 1 if ($Hemi_{k,i} \leq SLL_{goal}$) \vee ($|\phi_o - \phi_k| \leq BW_{\phi} \wedge |\theta_o - \theta_k| \leq BW_{\theta}$) LL compliance

DESIGN

ElementGain(0-deg) = 8	$f \approx 8.4\text{ GHz}$	element pattern file & frequency	$G_{array} = 26.6$	maximum possible array gain (dBiC)
SLLgoal ≈ -12.5		peak sidelobe compliance level	SLLcompliance = 99.9 %	SLL compliance
$\theta_0 \approx 30\text{-deg}$	$\phi_0 \approx 90\text{-deg}$	selected beam steering angles	MBG = 25.2	scanned main beam gain (dBiC)
nbits ≈ 4		# of phase shifter bits	HPBW $_{\phi} = 15\text{ deg}$	HPBW $_{\theta} = 8\text{ deg}$
MagErr ≈ 1.7	PhaseErr $\approx 30\text{-deg}$	random magnitude error (dB) & random phase errors	$\eta = 63.24\%$	D = 1 ft
N ≈ 72		# of elements (1,8,21,40,64)	s = 1.123 in	D = 12 in
				array efficiency & diameter
				required min spacing

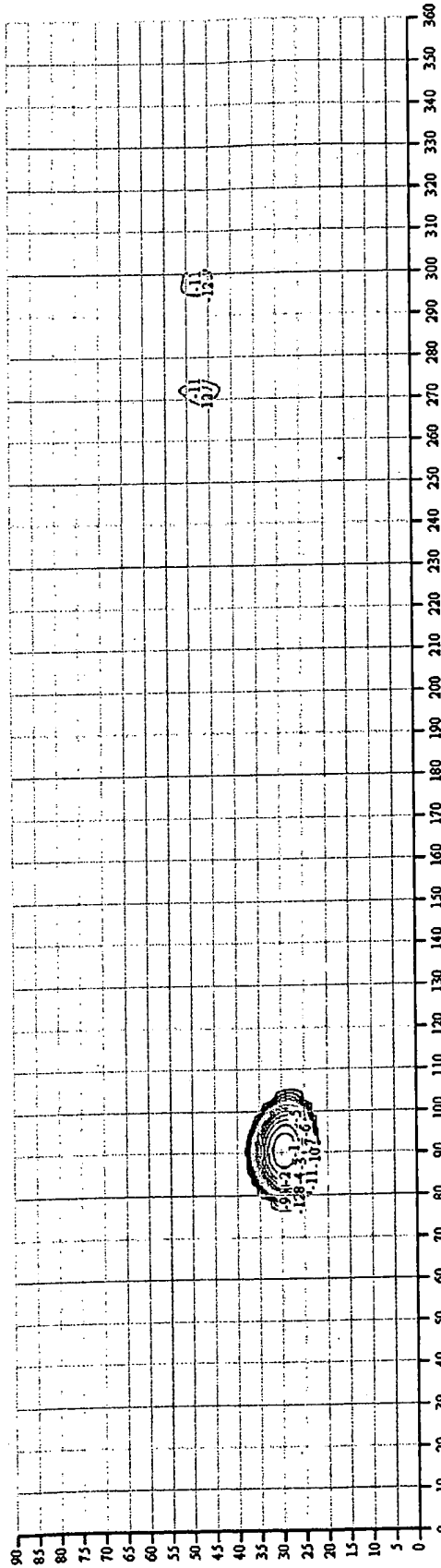
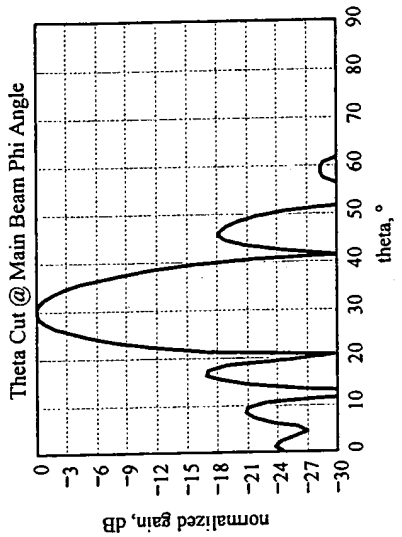
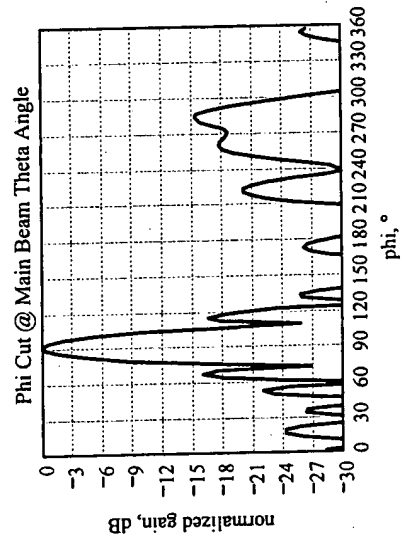
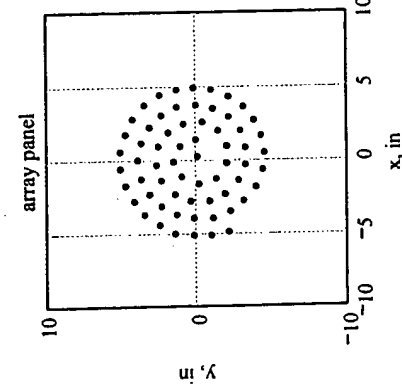




Hemi

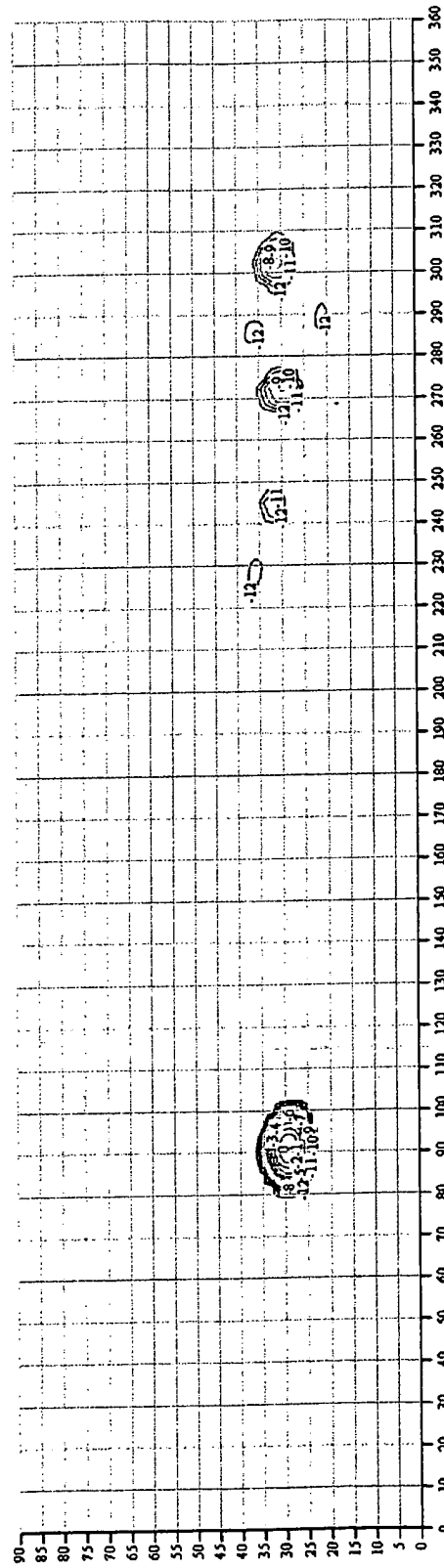
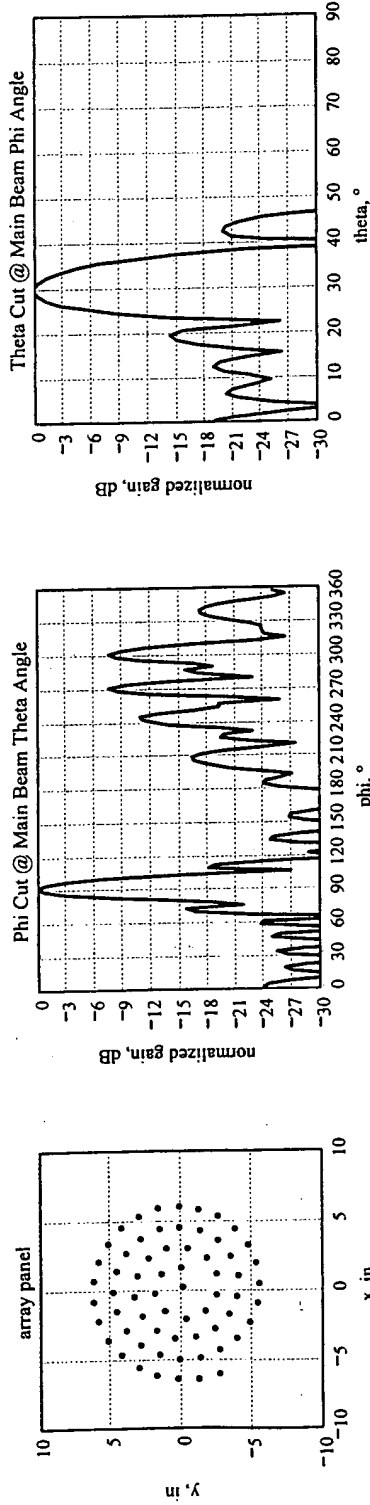
Not on chart

$f = 8.4 \text{ GHz}$
 $\text{Element Gain (0 deg)} = 19.5$
 $\text{SLL goal} = -12.5$
 $\theta_0 = 30\text{-deg}$
 $\phi_0 = 90\text{-deg}$
 $\text{nbits} = 4$
 $\text{MagErr} = 1.7$
 $\text{PhaseErr} = 30\text{-deg}$
 $\lambda \cdot D^{-1} = 6.68\text{deg}$
 $\text{element gain \& frequency}$
 $\text{peak sidelobe compliance level}$
 $\text{selected beam steering angles}$
 $\text{\# of phase shifter bits}$
 $\text{random magnitude error (dB) \& random phase errors}$
 $\text{\# of elements (1,8,21,40,64)}$
 boresight HPBW
 $G_{\text{array}} = 26.6$
 $\text{SLL compliance} = 29.7\%$
 $\text{MBG} = 24.9$
 $\text{HPBW}_\phi = 15\text{deg}$
 $\text{HPBW}_\theta = 9\text{deg}$
 $\eta = 62.398\%$
 $D = 1 \text{ ft}$
 $s = 1.19 \text{ in}$
 $\text{maximum possible array gain (dBiC)}$
 SLL compliance
 $\text{scanned main beam gain (dBiC)}$
 HPBW's
 $\text{array efficiency \& diameter}$
 $\text{required minimum element spacing}$



Not on chart

$f = 8.4 \text{ GHz}$
 $\text{SLL goal} = -12.5$
 $\theta_0 = 30 \text{ deg}$
 $n_{\text{bits}} = 4$
 $\text{MagErr} = 1.7$
 $\lambda \cdot D^{-1} = 1.02 = 5.513 \text{ deg}$
 $\text{element gain \& frequency}$
 $\text{peak sidelobe compliance level}$
 $\text{selected beam steering angles}$
 $\# \text{ of phase shifter bits}$
 $\text{random magnitude error (dB) \& random phase errors}$
 $\# \text{ of elements (1,8,21,40,64)}$
 boresight HPBW
 $C_{\text{array}} = 28.4$
 $\text{SLL compliance} = -38.9 \text{ dB}$
 $\text{MBG} = 25.6$
 $\text{HPBW}_\phi = 12 \text{ deg}$
 $\text{HPBW}_\theta = 8 \text{ deg}$
 $\eta = 62.398\%$
 $D = 1.2 \text{ ft}$
 $s = 1.47 \text{ in}$
 $\text{maximum possible array gain (dBIC)}$
 SLL compliance
 $\text{scanned main beam gain (dBIC)}$
 HPBW's
 $\text{array efficiency \& diameter}$
 $\text{required minimum element spacing}$



Hemi

Row6 @ 8.4 GHz

$f = 8.4 \text{ GHz}$

element gain & frequency

$\lambda \cdot D^{-1} \cdot 1.02 = 5.499 \text{ deg}$

boresight HPBW

lattice = "archimed.txt"

lattice filename

Gain = 28.4

maximum possible array gain (dBIC)

SLLgoal = -12.5

peak sidelobe compliance level

Sidelobe compliance = 98.9%

SLL compliance & peak SLL (dB)

nbits = 4

$\theta_0 = 30 \text{ deg}$

selected beam steering angles

MBG = 25.6

scanned main beam gain (dBIC)

of phase shifter bits

of phase shifter bits

HPBW $_{\phi} = 12 \text{ deg}$

main beam HPBW's

MagErr = 1.7

PhaseErr = 30-deg

uniform random magnitude (dB) & phase errors

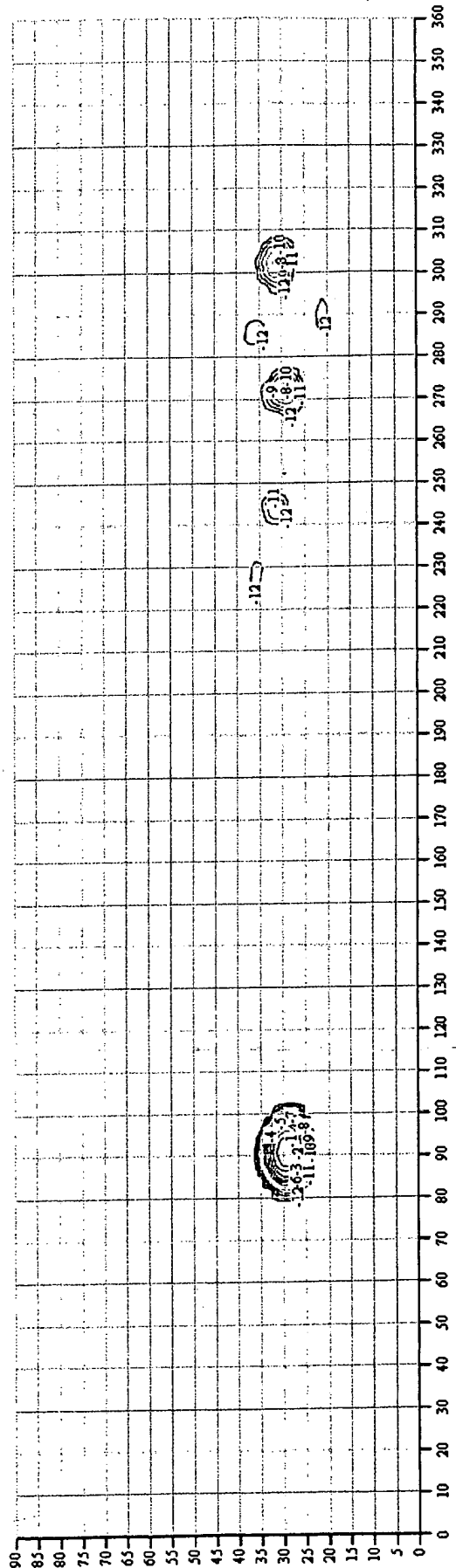
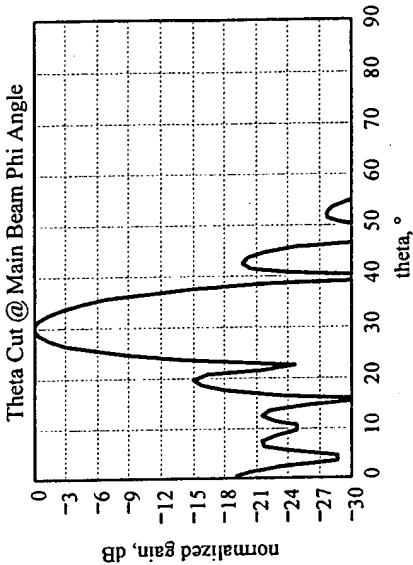
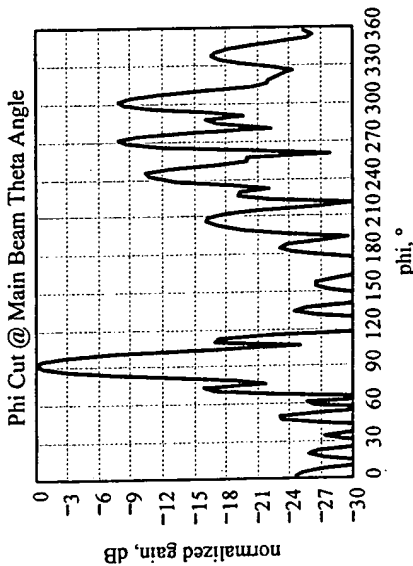
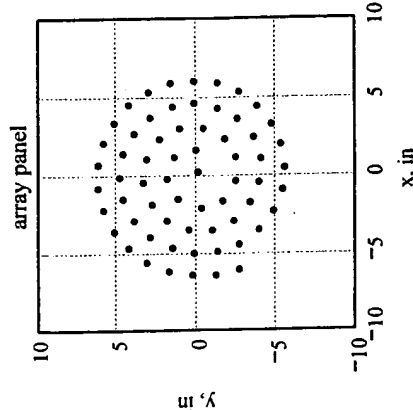
$\eta = 62\%$

array efficiency & diameter

of elements

$s = 1.47 \text{ in}$

required minimum element spacing



Hemi

Row7 @ 8.4 GHz

f = 8.4 GHz

element gain & frequency

$\lambda \cdot D^{-1} \cdot 1.02 = 5.427 \text{deg}$

boresight HPBW

lattice = "juniper.txt"

lattice filename

Gain = 28.4

maximum possible array gain (dBIC)

SLLgoal = -12.5

peak sidelobe compliance level

SLL compliance = 98%

SLL compliance & peak SLL (dB)

$\theta_0 \approx 30 \text{deg}$

selected beam steering angles

MBG = 25.6

scanned main beam gain (dBIC)

nbits = 4

of phase shifter bits

HPBW $_{\phi}$ = 9 deg

main beam HPBW

MagErr = 1.7

uniform random magnitude (dB) & phase errors

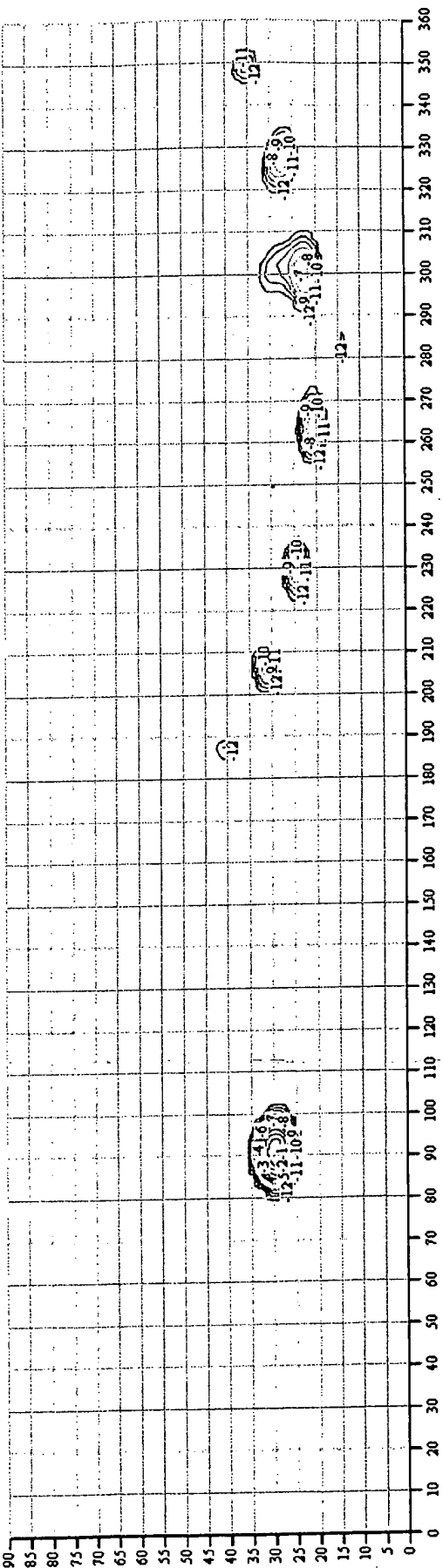
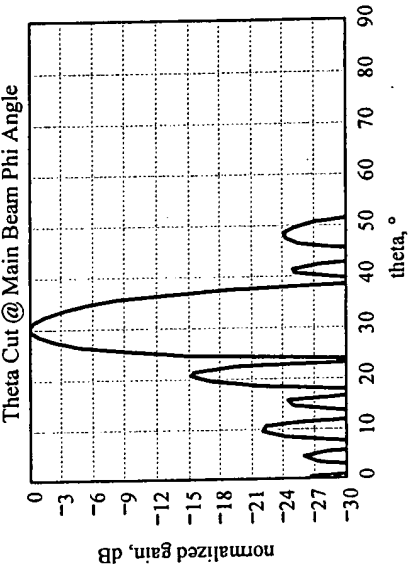
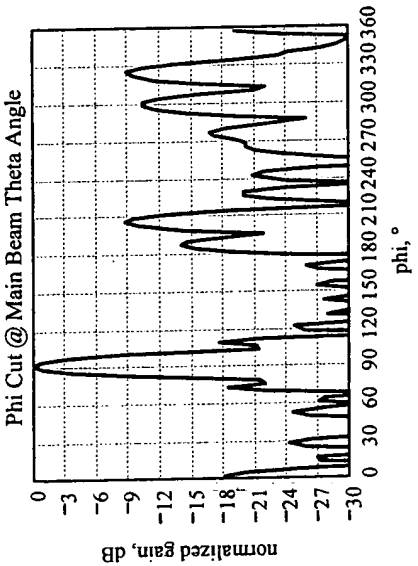
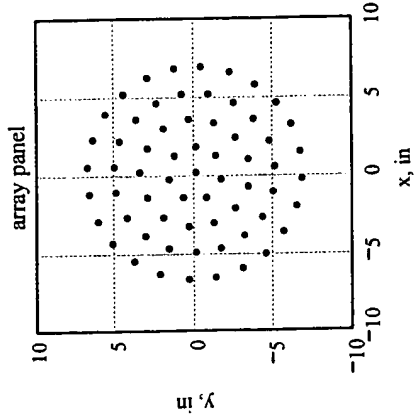
$\eta = 60.4\%$

array efficiency & diameter

of elements

s = 1.47in

required minimum element spacing



Hemi

4

Row2 @ 8.4 GHz

element gain (dB) = 16.92

f = 8.4 GHz

element gain & frequency

lattice = "tri96.txt"

lattice filename

SLLgoal = -12.5

peak sidelobe compliance level

$\theta_0 = 30$ deg

selected beam steering angles

nbits = 4

of phase shifter bits

MagErr = 1.7

PhaseErr = 30-deg

uniform random magnitude (dB) & phase errors

N = 96

of elements

s = 0.99in

$\eta = 75.4\%$

D = 11.69in

array efficiency & diameter

required minimum element spacing

$\lambda \cdot D^{-1} \cdot 1.02 = 7.4$ deg

boresight HPBW

Carray = 26.7

maximum possible array gain (dBIC)

SLL compliance = 100%

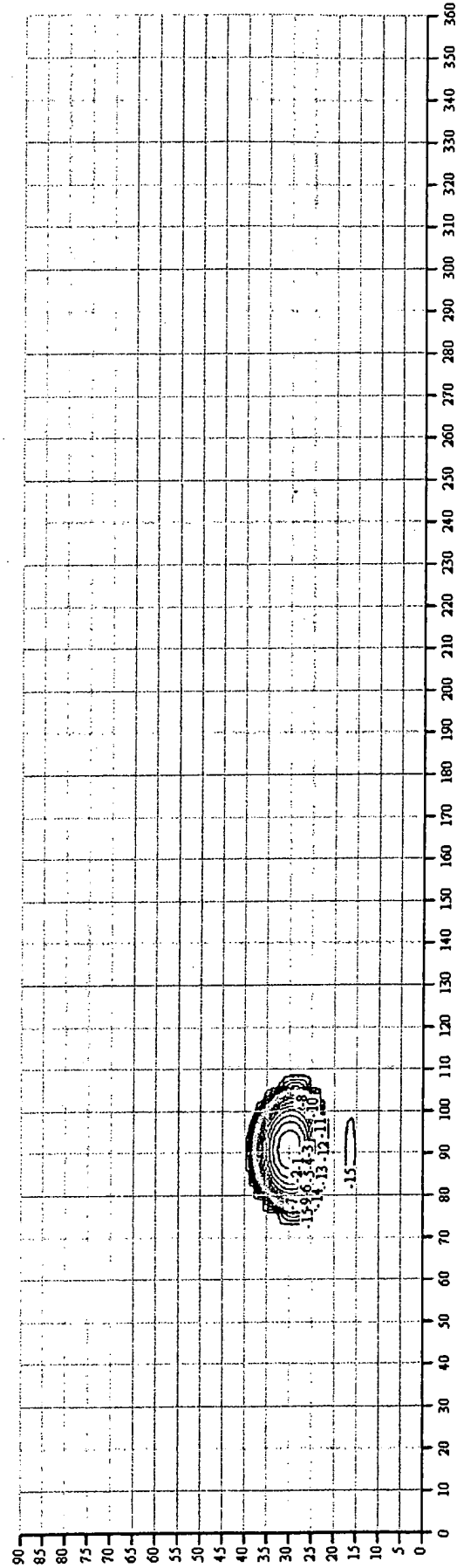
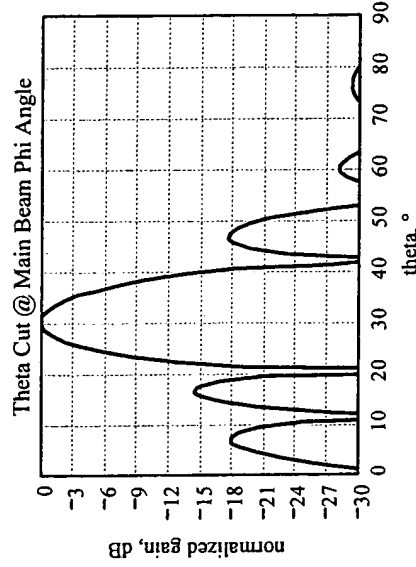
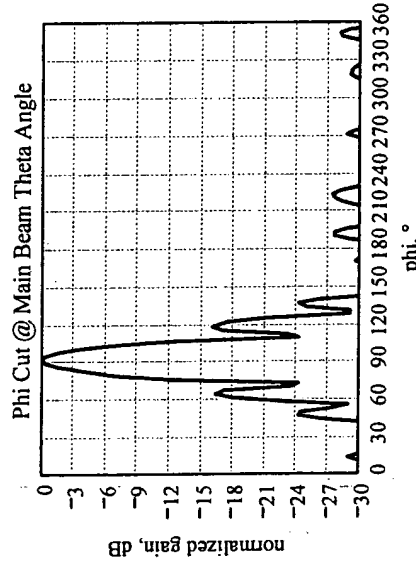
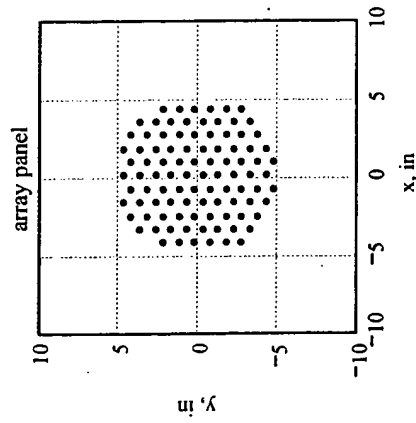
SLL compliance & peak SLL (dB)

MBG = 25.75

scanned main beam gain (dBIC)

HPBW $_{\phi} = 15$ deg

main beam HPBW $_{\theta}$ = 9deg



Hemi

NOT ON CHART

Element 0 tri 96 deg = 27.1

f = 8.4 GHz

element gain & frequency

$\lambda \cdot D^{-1} \cdot 1.02 = 7 \text{ deg}$

boresight HPBW

lattice = "tri96.txt"

lattice filename

$G_{\text{array}} = 27.1$

maximum possible array gain (dB(C))

SLLgoal = -12.5

peak sidelobe compliance level

SLL compliance = 100%

Peak SLL = -14.5

SLL compliance & peak SLL (dB)

$\theta_0 = 30 \text{ deg}$

$\phi_0 = 90 \text{ deg}$

selected beam steering angles

MBG = 26

scanned main beam gain (dB(C))

nbits = 4

of phase shifter bits

HPBW $\phi = 15 \text{ deg}$

main beam HPBW

MagErr = 1.7

PhaseErr = 30 deg

uniform random magnitude (dB) & phase errors

$\eta = 75.4\%$

D = 1 ft

array efficiency & diameter

N = 96

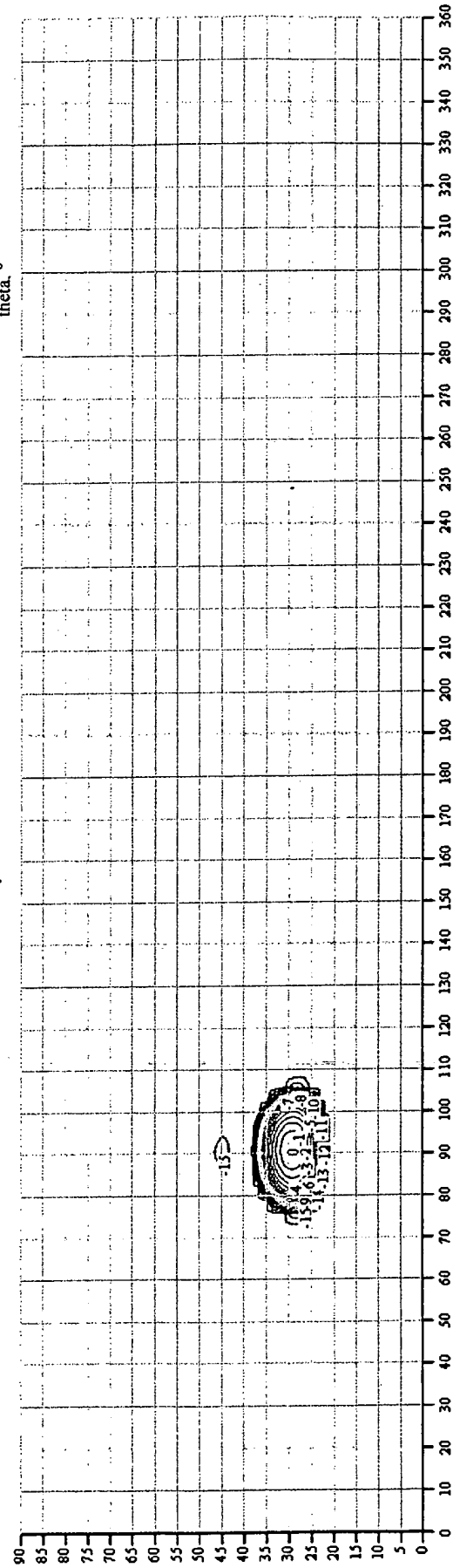
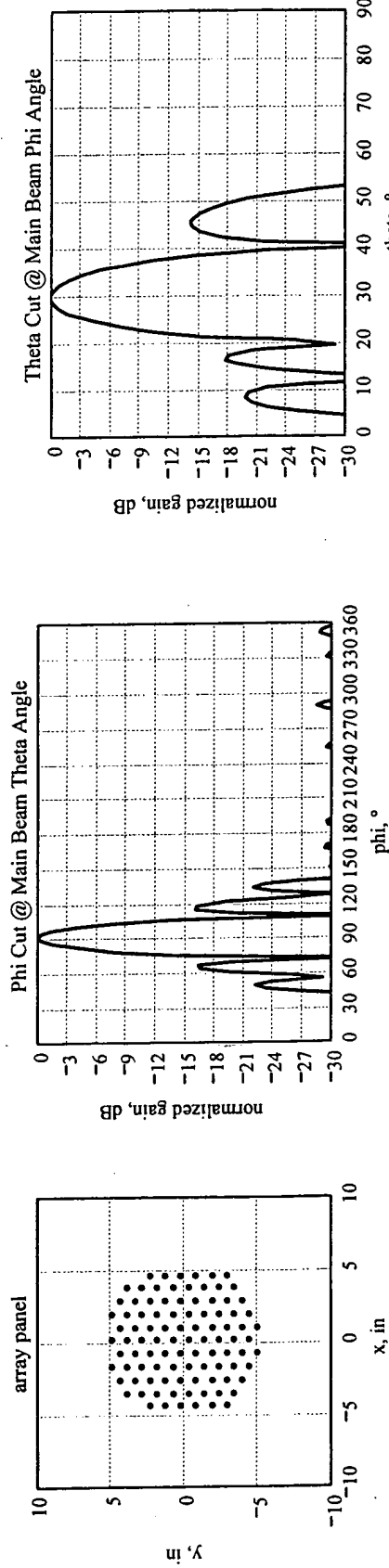
s = 1.039 in

required minimum element spacing

array panel

Phi Cut @ Main Beam Theta Angle

Theta Cut @ Main Beam Phi Angle



Hemi

6

Row5 @ 8.4 GHz

element gain (dBi) = 15.5

f = 8.4 GHz

element gain & frequency

lattice = "lat72.txt"

lattice filename

SLL goal = -12.5

peak sidelobe compliance level

$\theta_0 = 30$ -deg

$\phi_0 = 90$ -deg

selected beam steering angles

nbits = 4

of phase shifter bits

MagErr = 1.7

PhaseErr = 30-deg

uniform random magnitude (dB) & phase errors

N = 72

of elements

$$\lambda D^{-1} \cdot 1.02 = 8.011 \text{deg}$$

boresight HPBW

$$G_{\text{array}} = 25.897$$

maximum possible array gain (dBiC)

$$\text{SLL compliance} = 99.9\%$$

SLL compliance & peak SLL (dB)

$$\text{MBG} = 24.733$$

scanned main beam gain (dBiC)

$$\text{HPBW}_{\phi} = 15 \text{deg} \quad \text{HPBW}_{\theta} = 11 \text{deg}$$

main beam HPBWs

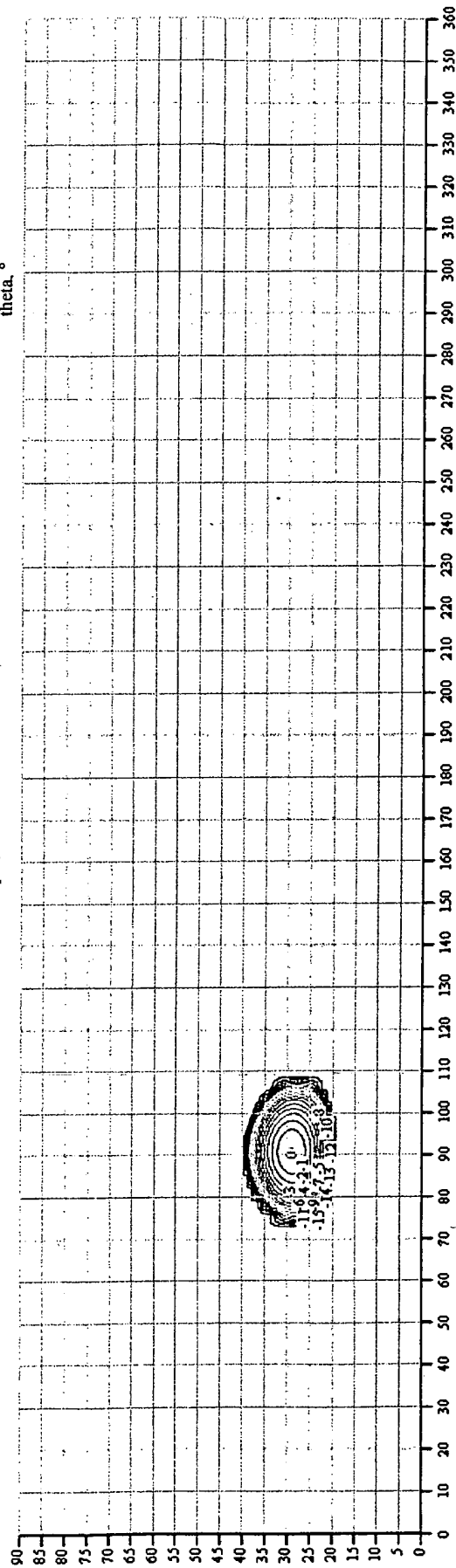
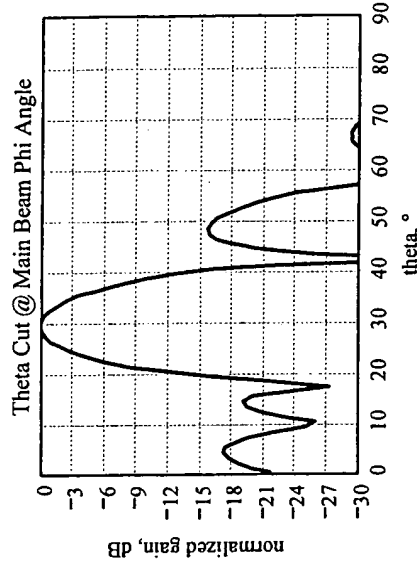
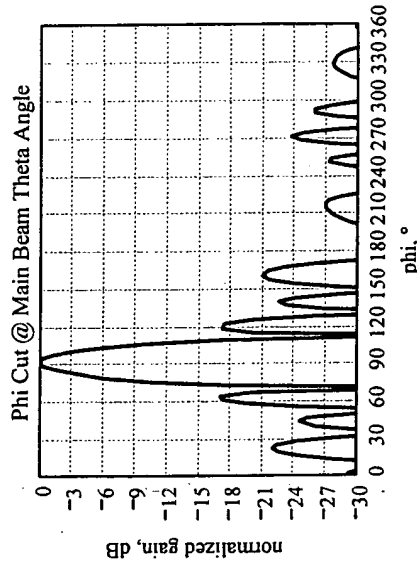
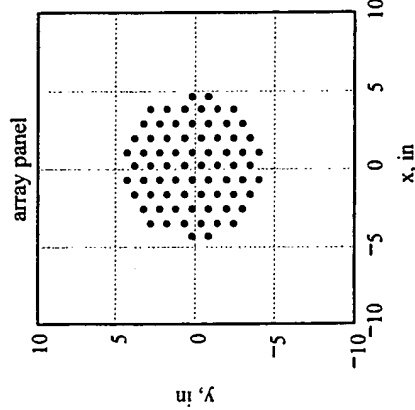
$$\eta = 74.02\%$$

array efficiency & diameter

$$D = 0.9 \text{ft}$$

$$s = 1.039 \text{in} \quad s = 0.74\lambda$$

required minimum element spacing



Hemi

72 element triangular lattice scaled 1.05 - scanned to $\phi=60^\circ$ (worst case not $\phi=90^\circ$)

lattice filename
 element gain & frequency
 $f = 8.4 \text{ GHz}$

lattice \approx "lat72.txt"

SLL goal ≈ -12.5

$\theta_0 \approx 30\text{-deg}$ $\phi_0 \approx 60\text{-deg}$

nbits ≈ 4

MagErr ≈ 1.7 PhaseErr $\approx 30\text{-deg}$

$\lambda \cdot D^{-1} \cdot 1.02 = 8.011\text{deg}$

$C_{\text{array}} = 25.897$

Side compliance $\approx 100\%$

MBG = 24.768

$\text{HPBW}_\phi = 17.7\text{deg}$ $\text{HPBW}_\theta = 10.5\text{deg}$

$\eta = 74.02\%$ $D = 0.9\text{ft}$

$s = 1.039\text{in}$ $s = 0.74\lambda$

theoretical boresight HPBW

maximum possible array gain (dBiC)

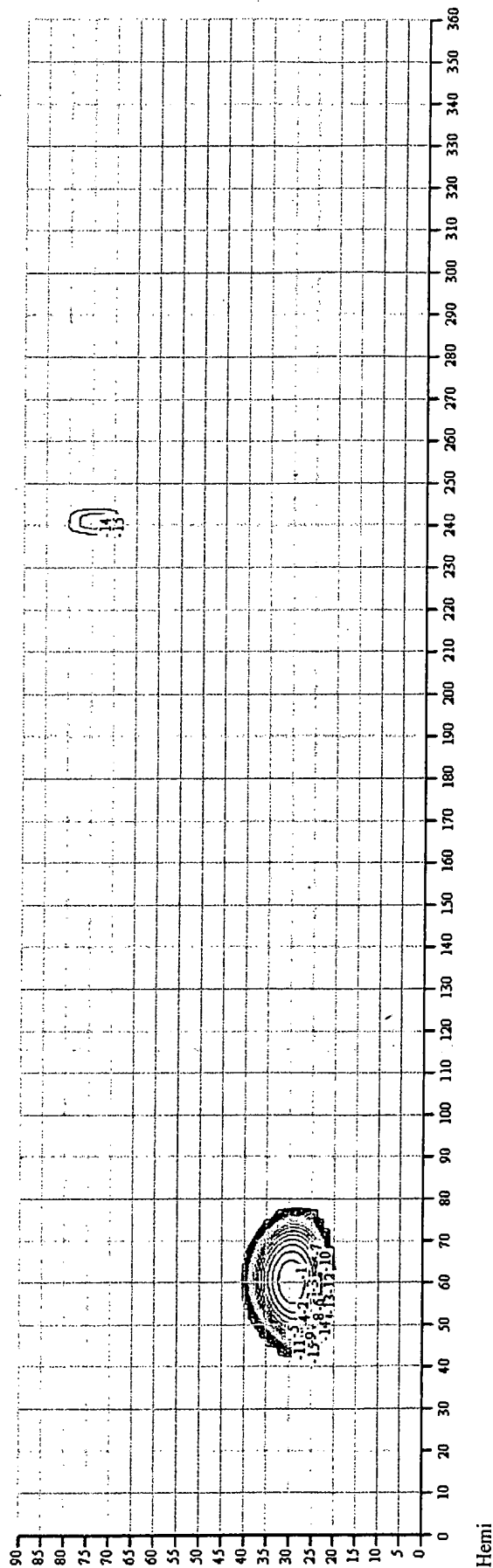
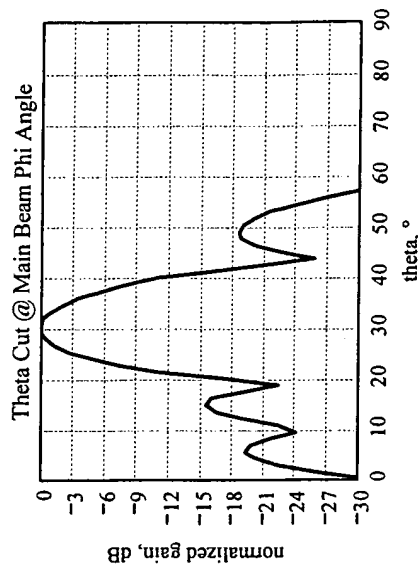
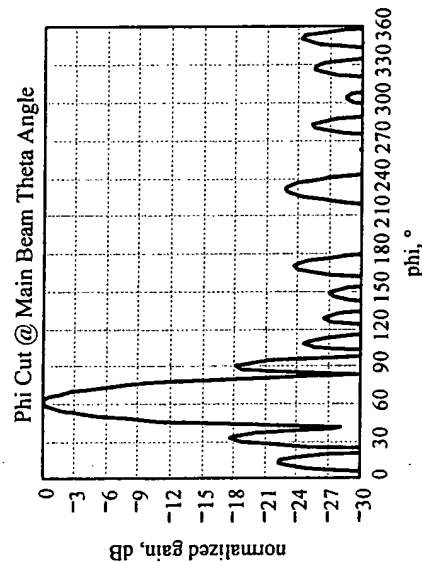
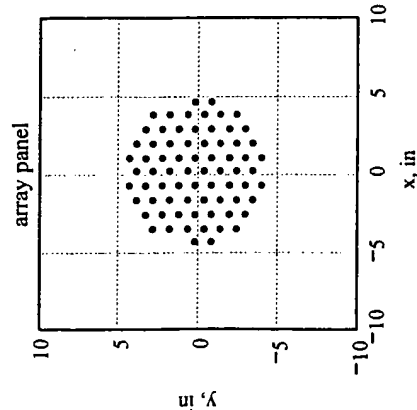
SLL compliance & peak SLL (dB)

scanned main beam gain (dBiC)

main beam HPBW's

array efficiency & diameter

required minimum element spacing



Hemi

64 element archimedes spiral lattice with 7.78 dB elements - scanned to $\phi=60^\circ$ (worst case?)

lattice filename
 element gain & frequency
 $f = 8.4 \text{ GHz}$

lattice filename
 peak sidelobe compliance level

SLLgoal ≈ -12.5

$\theta_0 \approx 30\text{-deg}$ $\phi_0 \approx 60\text{-deg}$

nbits ≈ 4

MagErr ≈ 1.7 PhaseErr $\approx 30\text{-deg}$

of elements

of phase shifter bits

uniform random magnitude (dB) & phase errors

$\lambda \cdot D^{-1} \cdot 1.02 = 7.378\text{deg}$

$C_{array} = 25.843$

SLL compliance $\approx 100\%$

MBG ≈ 24.536

HPBW $_{\phi} = 16\text{deg}$ HPBW $_{\theta} = 9.7\text{deg}$

$\eta = 62.013\%$ $D = 0.9\text{ft}$

$s = 1.096\text{in}$ $s = 0.78\lambda$

theoretical boresight HPBW

maximum possible array gain (dBIC)

SLL compliance & peak SLL (dB)

scanned main beam gain (dBIC)

main beam HPBW

array efficiency & diameter

required minimum element spacing

